Plant-Related Factors Influence the Effectiveness of *Neoseiulus fallacis* (Acari: Phytoseiidae), a Biological Control Agent of Spider Mites on Landscape Ornamental Plants

P. D. PRATT,[1] R. ROSETTA,[2] AND B. A. CROFT[3]

USDA/ARS and University of Florida, 3205 College Avenue, Fort Lauderdale, FL 33314

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ABSTRACT The predatory mite *Neoseiulus fallacis* (Garman) was evaluated as a biological control agent of herbivorous mites on outdoor-grown ornamental landscape plants. To elucidate factors that may affect predator efficiency, replicated tests were conducted on 30 ornamental plant cultivars that varied in relationship to their generalized morphology (e.g., conifers, shade trees, evergreen shrubs, deciduous shrubs, and herbaceous perennials), production method (potted or field grown), canopy density, and the prey species present on each. Plant morphological grouping and foliar density appeared to be the most influential factors in predicting successful biological control. Among plant morphological groups, *N. fallacis* was most effective on shrubs and herbaceous perennials and less effective on conifers and shade trees. *N. fallacis* was equally effective at controlling spider mites on containerized (potted) and field grown plants, and there was no difference in control of mites on plants with *Tetranychus* spp. versus those with *Oligonychus* or *Schizotetranychus* spp. Moderate to unsuccessful control of spider mites by *N. fallacis* occurred mostly on tall, vertical plants with sparse canopies. Acceptable spider mite control occurred in four large-scale releases of *N. fallacis* into production plantings of *Abies procera, Thuja occidentalis* 'Emerald', *Malus* rootstock, and *Viburnum plicatum* 'Newport'. These data suggest that *N. fallacis* can be an effective biological control agent of multiple spider mite species in a range of low-growing and selected higher growing ornamental plants.

KEY WORDS Phytoseiidae, Tetranychidae, predatory mites, nursery

PREDATORY MITES IN the family Phytoseiidae are important biological control agents of plant-inhabiting pest mites, particularly those in the Tetranychidae (Helle and Sabelis 1985, McMurtry and Croft 1997). Inoculative releases of these predatory mites into agroecosystems have resulted in local suppression of spider mite populations and a decreased reliance on miticides (Croft 1990). Releases of the biological control agent *Neoseiulus fallacis* (Garman), for instance, can result in suppression of pest mites on hops, peppermint, and strawberry in the Pacific Northwest of North America (Strong and Croft 1995, Morris et al. 1996, Croft and Coop 1998). Recently, *N. fallacis* was selected for evaluation as a control agent of multiple spider mite species in the diverse cropping system of outdoor-grown ornamental landscape plants in this region (Pratt 1999, Pratt and Croft 2000a).

Unfortunately, little is known concerning the compatibility of *N. fallacis* with plants grown in ornamental systems. Studies have demonstrated that phytoseiids and their prey are sensitive to plant architecture (Pratt et al. 1998, Skirvin and De Courcy Williams 1999). Plant morphology, including trichomes, acarodomatia, and nectaries, may directly affect leaf residency time and ultimately biological control success (Walter and O'Dowd 1992, Pemberton 1993, English-Loeb et al. 1999). In addition, phytoseiids are vulnerable to low humidity, which may be mitigated by foliar density within plant canopies (Croft et al. 1993). Responses to plant incompatibility may include emigration (dispersal) from the plant, thereby releasing spider mite populations from predation and resulting in excessive plant damage (Grevstad and Klepetka 1992, Kareiva and Sahakian 1990). McMurtry and Croft (1997) classified *N. fallacis* as a type II selective predator of tetranychids and suggested that this group may be more affected by plant features than more specialized predators of spider mites (i.e., *Phytoseiulus* spp.). Knowledge about the compatibility of *N. fallacis* with a range of plant species from many generalized morphological groups (e.g., conifer, evergreen shrub, deciduous shrub, shade tree, herbaceous perennial) produced in ornamental nursery systems is integral to the development of biological control tactics for these commodities (DeBach et al. 1976, Stiling 1993).

The objective of this study was to assess the ability of *N. fallacis* to suppress spider mites on a range of

[1] E-mail: prattp@saa.ars.usda.gov.

[2] Oregon State University, North Willamette Research and Extension Center, 15210 NE Miley Road, Aurora, OR 97002–9543.

[3] Oregon State University, Department of Entomology, 2046 Cordley Hall, Corvallis, OR 97331.

plants produced in outdoor ornamental nurseries of the Pacific Northwest. To do this, we first identified plants susceptible to spider mites from among the morphological groups grown in the region. Initially in small-scale tests, we inoculated *N. fallacis* into selected spider mite-infested plant canopies and quantified the level of pest suppression. We then selected a subset of these plants and performed large-scale releases of *N. fallacis* into production level plantings.

Materials and Methods

Predator Source and Release. Stocks of *N. fallacis* for laboratory cultures were initially collected from agricultural crops in the Willamette Valley, OR (Hadam et al. 1986). These cultures have been maintained for >6 yr with periodic additions from field-collected mites. In all experiments, predators came from a rearing facility at Oregon State University: *N. fallacis* were produced on lima beans (*Phaseolus lunatus* L.) infested with *Tetranychus urticae* Koch under greenhouse conditions of 26:21 (±5)°C day:night, 75% (±10) RH, and a photoperiod of 16:8 L:D (Strong and Croft 1995). Before release of predators, spider mites had nearly been eliminated on leaves. Predators were released by placing bean leaves containing known quantities of *N. fallacis* individuals directly into the canopy of selected plants that were infested with spider mites.

Small-Scale Tests. We selected 30 ornamental plants from among the generalized morphological groups of conifers, shade trees, evergreen shrubs, deciduous shrubs, and herbaceous perennials to quantify the ability of *N. fallacis* to suppress spider mites and reduce damage symptoms within their respective plant canopies. Experiments were conducted in northern Willamette Valley ornamental production facilities under typical cultural practices (Pratt and Croft 2000a). In all tests, ≥10 individual spider mite-infested plants were randomly assigned one of two treatments: release of *N. fallacis,* as described, or no release (control). A minimum of five replicate plants per treatment were used for each test.

To estimate mite densities over time, five randomly selected leaves or three branches (Table 1) were removed, without replacement, from each replicate for several weeks before and a minimum of 8 wk after the introduction of predators. Individual leaves or branches were placed into sealable plastic bags and held in a cooler chest during transport to the laboratory; mite densities were counted under a 40 × microscope within 24 h. All predators found on sampled branches were mounted on glass slides in Hoyer's medium, heated for 1 wk on a slide-warmer at 40°C, and identified according to morphological characteristics as described by Schuster and Pritchard (1963) using a 200 × phase-contrast microscope. All estimates of population densities are reported as mean (±SD).

Twelve weeks after release of the predators, control of spider mites by *N. fallacis* was categorized into four levels based on (1) visual inspection of plants, (2) the spider mite densities present at the end of each test, and (3) statistically significant reductions of pest mite population densities when compared with controls: 1 = unacceptable levels of spider mite control resulting in pronounced esthetic damage and unmarketable plants (>3 spider mites/leaf), 2 = acceptable spider mite control with only slight esthetic damage resulting in marketable plants (1–3 spider mites/leaf), 3 = acceptable spider mite control with no esthetic damage (<1 spider mite/leaf) and, 4 = 3, except reduction of spider mites to levels that were undetectable by our sampling method. In addition, we classified the foliar density of each plant canopy into one of three categories based on visual inspection: 1 = dense, 2 = moderate or 3 = sparse (Table 1).

Large-Scale Tests. *N. fallacis* was effective at suppressing spider mites on many plants in the small-scale experiments. However, extrapolation of data gathered from small-scale tests to production-level plantings remained uncertain because of greater variability experienced in production-level plantings with regard to predator release distributions, prey densities between plants, plant cultural conditions, and other factors relating to production and environmental conditions. Therefore, in 1998, we undertook large-scale inoculative releases of *N. fallacis* into production level plantings of *Abies procera, Thuja occidentalis* 'Emerald', *Malus* MM.106 EMLA rootstock, and *Viburnum plicatum* 'Newport'. Estimation of mite densities and predator identification were done as described earlier.

Abies procera. The study site consisted of a 0.5-ha planting of ≈2-m tall (8 yr old) *A. procera* trees located near Independence, OR (44.86 N and 123.2 W). Trees were planted on a 4% NW slope and spaced ≈2 m apart. Populations of the spruce spider mite, *Oligonychus ununguis* (Jacobi), were monitored weekly by sampling the branches from 40 randomly selected trees within the study site. Three randomly selected 10-cm terminal branches were removed from each tree at 0.5, 1, and 1.5 m above the soil surface. Samples were placed in an ice cooler, transported to the laboratory, and reviewed under a 40 × stereomicroscope. Data from stratified samples were averaged within a tree and ultimately among trees. On 8 May, spider mite densities reached 2.75 (±1.02) mites per branch, and 8,000 adult female *N. fallacis* were evenly distributed on trees within the study site.

Thuja occidentalis [Emerald]. The study site was near Woodburn, OR (45.14°N and 122.5°W) and consisted of 500 field-planted *T. occidentalis* 'Emerald' trees. Plants were 1.25 (±0.11) m tall, spaced ≈1 m, and irrigated with overhead sprinklers as needed. Spruce spider mites were monitored on 25 randomly selected trees by removing two terminal branches of 4 cm in length located at 0.5 and 1 m above the soil surface. On 12 June, spider mite densities reached 1.23 (±0.64) per branch, and 3,000 *N. fallacis* adult females were evenly distributed on plants throughout the study site.

Malus 'MM.106 EMLA' rootstock. The study site was near Gervais, OR (45.1°N and 122.8°W). *Malus* rootstocks (MM.106 EMLA) were cultivated in a 7.3-ha stoolbed field with 400 (±22) plants/m^2 and 1 m

Table 1. Biological control of spider mite pests by the predaceous mite *Neoseiulus fallacis* in a range of ornamental nursery plants

Ornamental plant	Family	Type[a]	Age[b]	Size[c]	Substrate[d]	Canopy density[e]	Release rate[f]	Release date	Spider mite	Pest Density[g]	Control[h]
Abies procera	Pinaceae	C	8	2.0 m	F	2	10	June 13	*O. ununguis*[i]	3/B[j]	1
Acer × freemanii 'Jeffersred'	Aceraceae	ST	1	1.0 m	F	1	3	July 10	*T. urticae*	1/L	1
Astilbe simplicifolia 'Sprite'	Saxifragaceae	HP	1	3.8 L	C	3	3	June 20	*T. urticae*	0.9L	4
Azalea 'Vuyks Scarlet'	Ericaceae	ES	1	3.8 L	C	3	0.25	July 17	*T. urticae*	4/L	3
Buddleia davidii 'White Bouquet'	Buddlejaceae	DS	1	3.8 L	C	1	2	July 10	*T. urticae*	5/L	3
Euonymous alatus 'Compacta'	Celastraceae	DS	2	11.3 L	C	2	2	July 18	*T. urticae*	5/L	4
Geranium cinereum 'Ballerina'	Geranuaceae	HP	1	3.8 L	C	3	2	June 20	*T. urticae*	10/L	3
Geum chiloense 'Georgenberg'	Rosaceae	HP	1	3.8 L	C	1	5	June 30	*T. urticae*	1/L	3
Hemerocalis 'Happy Returns'	Hemerocallidaceae	HP	1	3.8 L	C	1	2	June 30	*T. urticae*	2/L	2
Ilex crenata 'Convexa'	Aquifoliaceae	DS	1	3.8 L	C	2	5	June 25	*T. urticae*	3/L	4
Magnolia stelleta 'Royal Star'	Magnoliaceae	DS	2	0.8 m	F	1	1	July 8	*T. urticae*	2/L	1
Malus 'EMLA 106'	Rosaceae	R	1	0.6 m	F	3	4000/ha	June 27	*T. urticae*	0.6/L	4
Picea glauca 'Conica'	Pinaceae	C	1	3.8 L	C	3	5	June 30	*O. ununguis*	4/B	2
Potentilla fruticosa 'Gold Finger'	Rosaceae	DS	1	3.8 L	C	2	5	June 25	*T. urticae*	4/L	4
Potentilla fruticosa 'Gold Finger'	Rosaceae	DS	2	11.3 L	C	3	2	July 18	*T. urticae*	2/L	3
Rhododendron 'Ana Kruschke'	Ericaceae	ES	4	0.6 m	F	2	2	June 17	*O. illicis*	1/L	3
Rhododendron 'Hotie'	Ericaceae	ES	4	0.6 m	F	2	2	June 17	*O. illicis*	5/L	3
Salvia superba 'East Friesland'	Labiatae	HP	1	3.8 L	C	3	3	June 30	*T. urticae*	0.9/L	3
Sasaella hidaensis 'Murai'	Gramineae	ES	2	3.8 L	C	2	3	June 11	*S. longus*	2/L	4
Skimmia Japonica 'Female'	Rutaceae	ES	2	7.6 L	C	2	10	June 25	*P. citri*	12/L	3
Skimmia Japonica 'Female'	Rutaceae	ES	2	7.6 L	C	2	0.5	July 2	*T. urticae*	1/L	3
Spiraea bumalda 'Crispa'	Rosaceae	DS	2	0.6 m	F	3	5	July 2	*T. urticae*	2/L	3
Spiraea bumalda 'Gold Mound'	Rosaceae	ES	2	3.8 L	C	3	2	July 5	*T. urticae*	1/L	3
Thuja occidentalis 'Little Giant'	Cupressaceae	C	2	3.8 L	C	3	3	April 14	*O. ununguis*	2/B[k]	1
Thuja occidentalis 'Little Giant'	Cupressaceae	C	2	3.8 L	C	3	3	June 15	*O. ununguis*	10/B[k]	2
Tilia cordata 'Greenspire'	Tiliaceae	ST	1	0.9 m	F	1	2	July 2	*T. urticae*	2/L	1
Viburnum opulus 'Sterile'	Caprifoliaceae	DS	1	3.8 L	C	2	2	July 2	*T. urticae*	3/L	3
Viburnum plicatum 'Newport'	Caprifoliaceae	DS	2	0.25 m	F	3	3	June 15	*T. urticae*	5/L	2
Weigela florida 'Red Java'	Caprifoliaceae	DS	1	3.8 L	C	2	2	June 26	*T. urticae*	4/L	3
Weigela florida 'Verigata'	Caprifoliaceae	DS	1	3.8 L	C	2	5	July 2	*T. urticae*	8/L	3

[a] C, conifer; ES, evergreen shrub; DS, deciduous shrub; ST, shade tree; HP, herbaceous perennial

[b] Age of plants in years.

[c] Plant size described as height (m) or container size (L).

[d] F, field planted; C, plastic container

[e] Categories of foliar density in plant canopy: 1=dense, 2=moderate, 3=sparse.

[f] Number of predators released per plant or per ha

[g] Number of spider mites per leaf (L) or branch (B) at date of release.

[h] 1 = unacceptable levels of spider mite control resulting in pronounced aesthetic damage and unmarketable plants (>3 spider mites per leaf); 2 = acceptable spider mite control with only slight aesthetic damage resulting in marketable plants (<3 spider mites/leaf); 3 = acceptable spider mite control with no aesthetic damage (<1 spider mite/leaf); and 4 = 3 except reduction of spider mites to levels that were undetectable by our sampling method.

[i] Pest species: *Oligonychus ununguis, Oligonychus illicis, Panonychus citri, Schizotetranychus longus, Tetranychus urticae*

[j] Samples consist of 3 randomly selected, 10-cm terminal branches that were removed at 0.5, 1, 1.5 m above the soil surface

[k] Sample consists of a randomly selected, 4-cm branch.

between each row. Stoolbeds were rows of established root systems with sawdust drawn up along each row to cover roots and encourage growth of new branches (Hartmann and Kester 1983, Vasek and Howard 1984). Plants emerged from perennial roots in early spring, and by May, a continuous dense canopy of leaves was created within rows and nearly between rows. Rootstocks were sprinkler irrigated as needed according to soil moisture sensors. In fall, *Malus* rootstocks were harvested, sawdust replaced, and no plant material remained aboveground during winter. Mite densities were estimated by removing 400 leaves in an X pattern across the field every 14 d. When spider mites reached 0.22 (±0.05) per leaf, *N. fallacis* was released uniformly at a rate of 4,000 adult females/ha.

Viburnum plicatum 'Newport'. The study site was a 0.4-ha field of 2-yr-old *V. plicatum* 'Newport' shrubs near Dayton, OR (45.2°N and 123.1°W). The shrubs were planted in contiguous rows spaced ≈0.76 m apart. Mites were monitored by removing a single leaf from each linear meter of contiguous foliage. Spider mites reached 1.1 (±0.58) per leaf on 15 June, and 3,000 *N. fallacis* adult females were evenly distributed in the field. Irrigation of plants was performed as described above.

Statistical Analysis. Mite population densities among treatments in small-scale tests were compared over time with repeated measures analysis of variance (ANOVA) after a $\log(x + 1)$ transformation of the data (von Ende 1993). The Huynn-Feldt adjustment was used when the covariance matrix of data did not meet the assumption of sphericity (von Ende 1993, SAS Institute 1990). Multiple linear regression was used to quantify the influence of the plant morphological type, canopy density, production method and prey species on levels of spider mite control that was achieved by *N. fallacis* (SAS Institute 1990). Differences in mite control levels among morphological groups were compared with Fisher's least significant difference (LSD) (Ramsey and Schafer 1997). Caution should be used when drawing inferences from statistical comparisons among plant groups, production methods and pest genera because data were not adjusted for differences in plant size or other parameters that may influence biological control. For large-scale tests, statistical procedures were inappropriate because the maintenance of controls was not possible. For these tests, we plotted spider mite and predator densities over time.

Results and Discussion

Using the qualitative scale of spider mite control, the mean (±SD) score over all small-scale tests ($n = 30$) was 2.7 (±0.98), where 1 = unacceptable control, 2 = acceptable control with slight esthetic damage, 3 = acceptable control with no visible damage, and 4 = complete control. Of the variables tested, plant morphological grouping ($F = 21.41$; d.f. $_{1,\ 29}$; $P < 0.0001$) and canopy density ($F = 6.49$; d.f. $_{1,\ 29}$; $P < 0.0168$) were the only significant factors affecting the ability of *N. fallacis* to control spider mites among the assessed plants. Among plant types, *N. fallacis* was most effective on shrubs and herbaceous perennials and less effective on conifers and shade trees (Table 2). The observed differences in pest control may be related to the density of foliage and associated relative humidites within these plant canopies. *N. fallacis* is sensitive to the low relative humidities that may occur in sparsely canopied plants (Croft et al. 1993, Nyrop et al. 1998). More detailed investigations of canopy humidities and within-plant distributions of *N. fallacis* are needed to refine predictions of successful biological control in these plant systems.

Table 2. Biological control of spider mites among different plant types grown in ornamental nurseries.

Plant type	No. of tests	Control level[a] mean (±SD)
Shade tree	2	1.00 (0.00)a
Conifer	4	1.50 (0.58)a
Herbaceous perennial	5	3.00 (0.70)b
Deciduous shrub	12	3.08 (0.90)b
Evergreen shrub	7	3.14 (0.38)b
P-value		<0.0001[b]

Means followed by different letters are significant at $\alpha = 0.05$ (Fisher's LSD).

[a] See Table 1 for descriptions of levels.

[b] *P*-value derived from multiple linear regression $F = 21.41$; d.f.$_{1,\ 29}$.

Ornamentals are typically produced in individual plastic containers (pots) or planted directly into cultivated fields. In our studies, no significant difference was detected in the spider mite control levels between containerized versus field grown plants ($F = 2.25$; d.f. $_{1,\ 23}$; $P = 0.147$). However, maintaining long-term control of spider mite pests may depend on other factors that influence the survival of predatory mites in ornamental production systems. The base substrate on which containerized plants are usually placed consists of a coarse gravel bed, as compared with soil or turf in field-produced plants. Studies have shown that postdispersal survival of *N. fallacis* varies greatly when mites land on substrates other than plants. Jung and Croft (2000) found that survivorship was lowest when *N. fallacis* landed on gravel as compared with soil or turf. In addition, plant production may also affect multiseason conservation of phytoseiid predators (Pratt and Croft 2000b). In peppermint, *N. fallacis* moved to, or only survived in, leaf litter near the soil surface during winter (Morris et al. 1996). In potted ornamental plants, in contrast, overwintering *N. fallacis* females were recovered exclusively from above ground plant parts and not from soil and associated litter within pots (Pratt and Croft 2000b). These data suggest that overwintering survival of predators may be quite different among field-grown and containerized production nurseries.

An initial criterion for selecting *N. fallacis* as a biological control agent of spider mites was its ability to feed on many different tetranychid species (Pratt et al. 1999, Pratt and Croft 2000a). In these studies, no difference in control level was observed in comparisons between plants infested with *Tetranychus* and non-*Tetranychus* spp. ($F = 0.65$; d.f. $_{1,\ 23}$; $P = 0.427$), which

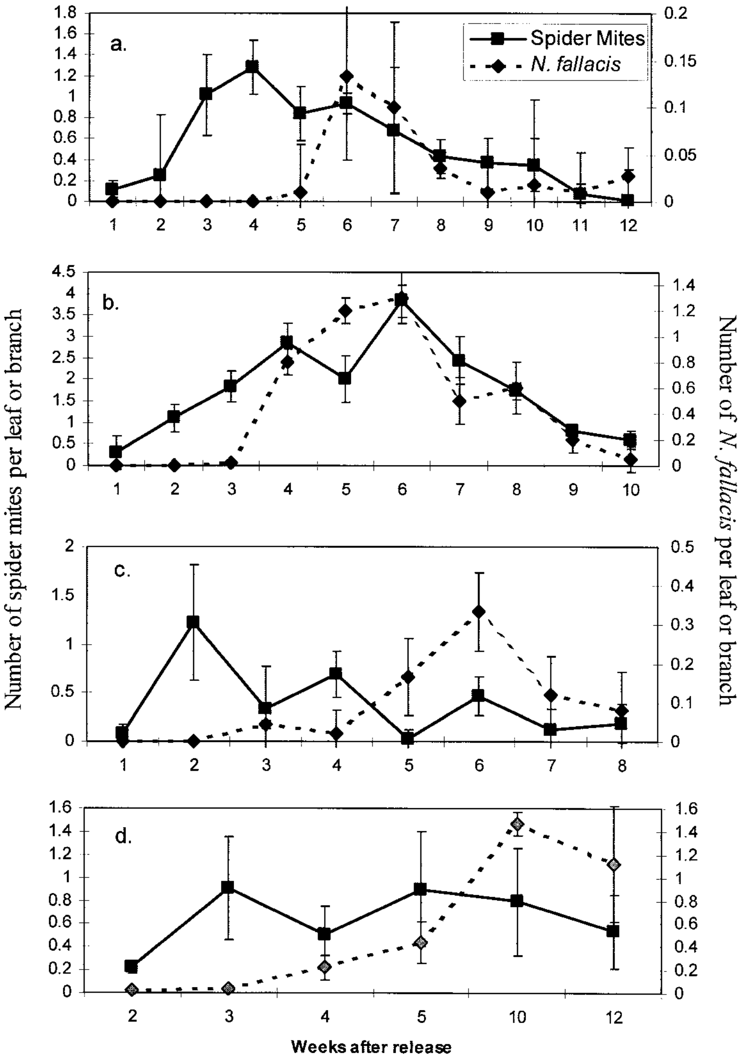

Fig. 1. Population trends of the predaceous mite *N. fallacis* and its prey *O. ununguis* (**b, c**) or *T. urticae* (**a, d**) in (**a**) *V. plicatum* 'Newport', (**b**) *A. procera,* (**c**) *T. occidentalis* 'Pyramidalis', and (**d**) *Malus* rootstock 'MM.106'. Data are presented as means ± SD

indicates that *N. fallacis* is effective against a range of tetranychid pests. These data are consistent with prey range tests that demonstrated *N. fallacis* readily feeds and reproduces on spider mites from several genera (Pratt et al. 1999). Also, these data support the classifications of *N. fallacis* as a selective type II predator of tetranychid mites; it being a group that shows a greater prey range than some species that have been commonly released in greenhouse and other high-value plant systems (e.g., *Phytoseiulus persimilis* A. H.; McMurtry and Croft 1997, Croft et al. 1998a, 1998b).

Acceptable levels of spider mite control occurred in all four large-scale inoculative releases of *N. fallacis.* In *V. plicatum* shrubs, *T. urticae* populations rose to 1.28 (±0.49) spider mites per leaf and were reduced to 0.35 (±0.26) 6 wk later; *N. fallacis* densities reached 0.13 (±0.06) 6 wk after release (Fig. 1a). Similarly, spider mites reached 3.83 (±1.1) per branch in *A. procera* trees but were suppressed to <1 per branch on week 9 (Fig. 1b). *Neoseiulus fallacis* effectively maintained *O. ununguis* populations at <1 mite per branch in *T. occidentalis* trees, and predator densities rose to 0.33 (±0.1) per leaf 1 mo later (Fig. 1c). In *Malus* rootstocks spider mites did not exceed 0.9 (±0.12) mites per leaf yet *N. fallacis* averaged 1.47 (±0.10) per leaf at week 8 (fig 1 d). Using the same evaluation criteria of control as for the small-scale tests (except without testing for significance between treatments), levels achieved by *N. fallacis* were the same or higher than in small-scale tests: *V. plicatum* = 3, *A. procera* = 2, *T. occidentalis* = 2, *Malus* = 3, overall mean = 2.5. Possibly a more important indicator of effectiveness, mite levels were sufficiently low in all four tests that production managers did not apply miticides. Overall, these large-scale tests indicated that in spite of the greater variation in predator release, plant culture, and environmental conditions, *N. fallacis* could respond or adapt to conditions and provide control of the pest. Such results indicated that large-scale use of such procedures in commercial nurseries would be successful.

Conclusions

Historically, selection of a phytoseiid for suppression of spider mites in high-value greenhouse or outdoor ornamental nursery crops has focused on type I specialist predators of *Tetranychus* spp. (e.g., *P. persimilis;* McMurtry 1982, Brushwein 1991, Cashion et al. 1994). Although these biological control agents can respond numerically to *Tetranychus* spp., they tend to disperse rapidly from plants as prey densities decrease and provide only short-term control (Helle and Sabelis 1985, Walzer and Schausberger 1999). To maintain adequate densities of *P. persimilis*, for instance, Cashion et al. (1994) made inundative releases at 2 wk intervals for control of *T. urticae* in croton (*Codiaeum variegatum* L.). Type I phytoseiids also have narrow prey ranges and may be ineffective at controlling other important spider mites (e.g., *Oligonychus* spp.) or other mite pests (e.g., Tarsonemidae) in ornamental systems (Pratt et al. 1999, McMurtry and Croft 1997).

The objective of our research was to develop a more sustainable biological control program for multiple spider mite pests of outdoor ornamentals in the Pacific Northwest. We hypothesized that a type II selective predator would enhance the long-term control of spider mites in these systems. *N. fallacis* was selected because it responds numerically and functionally to many different spider mite pests (Boyne and Hain 1983, Croft et al. 1998b, Pratt et al. 1999). Although *N. fallacis* does not provide control of *Tetranychus* spp. as quickly as some type I phytoseiids, its persistence in the crop of interest may be enhanced because it feeds on pollen, insects, and other alternative foods (McMurtry 1992, Pratt and Croft 2000a). In addition, *N. fallacis* is native to the growing region and overwinters on ornamentals (Hadam et al. 1986, Pratt and Croft 2000b). Here we have demonstrated that *N. fallacis* is capable of controlling spider mites in most ornamental types tested (Table 1), as indicated by an "acceptable" rating in 83% of the small-scale tests (Table 1) and in all large-scale field tests (Fig. 1).

Lower levels of control (i.e., less effective control) were obtained with releases of *N. fallacis* in tall, vertical-growing plants with sparse or moderate canopies. Under these circumstances, a more arid-adapted phytoseiid species may be better suited to the conditions on these plants. However, neither the dry-adapted *Galendromus occidentalis* (Nesbitt) nor *Neoseiulus californicus* McGregor was effective in similar tests conducted on shade trees (Pratt and Croft 2000a). Release of combinations of phytoseiid species that are more adapted to conditions on tall plant types may be useful in complex polycultures such as ornamental nurseries (Yao and Chant 1989, Walzer and Schausberger 1999).

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References Cited

Boyne, J. V., and F. P. Hain. 1983. Responses of *Neoseiulus fallacis* to different prey densities of *Oligonychus ununguis* and to different relative humidity regimes. Can. Entomol. 115: 1607–1614.

Brushwein, J. 1991. Spider mite IPM: Using the predatory mite, *Phytoseiulus persimilis*, to control twospotted spider mite, *Tetranychus urticae.* Fla. Foliage 11: 6–8.

Cashion, G. J., H. Bixler, and J. F. Price. 1994. Nursery IPM trials using predatory mites. Proc. Fla. State Hortic. Soc. 107: 220–222.

Croft, B. A. 1990. Arthropod Biological Control Agents and Pesticides. Wiley, New York.

Croft, B. A., and L. B. Coop. 1998. Heat units, release rate, prey density, and plant age effects on dispersal by *Neoseiulus fallacis* after inoculation into strawberry. J. Econ. Entomol. 91: 94–100.

Croft, B. A., W. B. Strong, R. H. Messing, and J. E. Dunley. 1993. Effects of humidity on eggs and immatures of *Neoseiulus fallacis, Amblyseius andersoni, Metaseiulus occidentalis* and *Typhlodromus pyri:* implications for biological control on apple, caneberry, strawberry and hop. Exp. Appl. Acarol. 17: 451–459.

Croft, B. A., L. N. Monetti and P. D. Pratt. 1998a. Comparative life histories and predation types: Are *Neoseiulus californicus* and *N. fallacis* similar type II selective predators of spider mites? Environ. Entomol 27: 531–538.

Croft, B. A., P. D. Pratt, G. Koskela, and D. Kaufman. 1998b. Predation, reproduction, and impact of phytoseiid mites (Acari:Phytoseiidae) on cyclamen mite, *Phytonemus pallidus* (Acari:Tarsonemidae) on strawberry. J. Econ. Entomol. 91: 1307–1314.

DeBach, P., C. B. Huffaker, and A. W. MacPhee. 1976. Evaluation of the impact of natural enemies, pp. 255–285. *In* C. B. Huffaker and P. S. Messenger [eds.], Theory and Practice of Biological Control. Academic Press, New York.

English-Loeb, G., A. P. Norton, D. M. Gadoury, R. C. Seem, and W. F. Wilcox. 1999. Control of powdery mildew in wild and cultivated grapes by a tydeid mite. Biol. Control 14: 97–103.

Grevstad, F. S., and B. W. Klepetka. 1992. The influence of plant architecture on the foraging efficiencies of a suite of ladybird beetles feeding on aphids. Oecologia 92: 399–404.

Hadam, J. J., M. T. Aliniazee, and B. A. Croft. 1986. Phytoseiid mites of major crops in Willamette Valley, Oregon, and pesticide resistance in *Typhlodromus pyri.* Environ. Entomol. 15: 1255–1263.

Hartmann, H. T., and D. E. Kester. 1983. Plant Propagation: Principles and Practices. Prentice Hall, Upper Saddle River, New Jersey.

Helle, W., and M. W. Sabelis. 1985. Spider Mites: Their Biology, Natural Enemies and Control, Vol. 1B. Elsevier, Amsterdam.

Jung, C. L., and B. A. Croft. 2000. Survival and plant–prey finding by *Neoseiulus fallacis* (Acari:Phytoseiidae) on soil substrates after aerial dispersal. Exp. Appl. Acarol. 24: 579–596.

Kareiva, P., and R. Sahakian. 1990. Tritrophic effects of a simple architectural mutation in pea plants. Nature 345: 433–434.

McMurtry, J. A. 1982. The use of phytoseiids for biological control: progress and future prospects, pp. 291–321. *In* M. A. Hoy [ed.] Recent advances in knowledge of the Phytoseiidae. Division of Agricultural Science, University of California, Berkeley, CA.

McMurtry, J. A. 1992. Dynamics and potential impact of 'generalist' phytoseiids in agroecosystems and possibilities for establishment of exotic species. Exp. Appl. Acarol. 14: 371–382.

McMurtry, J. A., and B. A. Croft. 1997. Life-styles of phytoseiid mites and their roles in biological control. Annu. Rev. Entomol. 42: 291–321.

Morris, M. A., B. A. Croft, and R. E. Berry. 1996. Overwintering and effects of autumn habitat manipulation and carbofuran on *Neoseiulus fallacis* and *Tetranychus urticae* in peppermint. Exp. Appl. Acarol. 20: 249–258.

Nyrop, J., G. English-Loeb, and A. Roda. 1998. Conservation biological control of spider mites in perennial cropping systems., pp. 307–333. *In* P. Barbosa [ed.], Conservation Biological Control. Academic Press, San Diego.

Pemberton, R. W. 1993. Observations of extrafloral nectar feeding by predaceous and fungivorous mites. Proc. Entomol. Soc. Wash. 95: 642–643.

Pratt, P. D. 1999. Biological control of spider mites by the predatory mite *Neoseiulus fallacis* (Acari: Phytoseiidae) in ornamental nursery systems. Ph. D. dissertation, Oregon State University, Corvallis.

Pratt, P. D., and B. A. Croft. 2000a. Screening of predatory mites as potential control agents of pest mites in landscape plant nurseries of the Pacific Northwest. J. Environ. Hortic. 18: 218–223.

Pratt, P. D., and B. A. Croft. 2000b. Overwintering and comparative sampling of *Neoseiulus fallacis* (Acari: Phytoseiidae) on ornamental nursery plants. Environ. Entomol. 29: 1034–1040.

Pratt, P. D., L. N. Monetti, and B. A. Croft. 1998. Within- and between-plant dispersal and distributions of *Neoseiulus californicus* and *N. fallacis* in simulated bean and apple branch systems. Environ. Entomol. 27: 148–153.

Pratt, P. D., P. Schausberger, and B. A. Croft. 1999. Prey-food types of *Neoseiulus fallacis* and literature versus experimentally-derived prey-food estimates for five phytoseiid species. Exp. Appl. Acarol. 23(7): 551–565.

Ramsey, F. L., and D. W. Schafer. 1997. The Statistical Sleuth. Duxbury Press, Belmont, CA.

SAS Institute. 1990. SAS/STAT User's guide, version 6, 4th ed. Cary, NC.

Schuster, R. O., and A. E. Pritchard. 1963. Phytoseiid mites of California. Hilgardia 34: 191–194.

Skirvin, D. J., and M. De Courcy Williams. 1999. Differential effects of plant species on a mite pest (*Tetranychus urticae*) and its predator (*Phytoseiulus persimilis*): implications for biological control. Exp. Appl. Acarol. 23: 497–512.

Stiling, P. 1993. Why do natural enemies fail in classical biological control programs? Am. Entomol 39: 31–37.

Strong, W. B., and B. A. Croft. 1995. Inoculative release of phytoseiid mites (Acarina: Phytoseiidae) into the rapidly expanding canopy of hops for control of *Tetranychus urticae* (Acarina: Tetranychidae). Environ. Entomol. 24: 446–453.

Vasek, J., and B. H. Howard. 1984. Effects of selective and diennial harvesting on the production of apple stoolbeds. J. Hortic. Sci. 59: 477–485.

von Ende, C. N. 1993. Repeated-measures analysis: growth and other time-dependent measures, pp. 113–137. *In* S. M. Scheiner and I. Gurevitch [eds.] Design and analysis of ecological experiments. Chapman & Hall, New York.

Walter, D. E., and D. J. O'Dowd. 1992. Leaves with domatia have more mites. Ecology 73: 1514–1518.

Walzer, A., and P. Schausberger. 1999. Predation preferences and discrimination between con- and heterospecific prey by the phytoseiid mites *Phytoseiulus persimilis* and *Neoseiulus californicus.* BioControl 43: 469–478.

Yao, D. S., and D. A. Chant. 1989. Population growth and predation interference between two species of predatory phytoseiid mites in interactive systems. Oecologia 80: 443–455.

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